Review Article

Foraging Behavior of Honey Bee in Niger [*Guizotia abyssinica* (L. f.) Cass.]: A Review

Abstract

Niger ~~plant is~~plants are highly dependent on pollination, particularly by honey bees (*Apis* spp. ~~*spp.*~~), for ~~enhanced~~increased seed yield and genetic diversity. Honey bees, ~~being~~ the most efficient pollinators of niger, exhibit distinct foraging behaviors influenced by multiple factors, including floral rewards, diurnal activity patterns, environmental conditions and competition with other pollinators. Their foraging activity is characterized by peak visitation rates during the morning hours, typically between 9:00 AM and 1:00 PM, when nectar secretion is at its maximum and weather conditions are optimal. Nectar and pollen collection are vital for both colony sustenance and crop pollination, with honey bees displaying remarkable flower constancy, a behavior that enhances pollination efficiency and cross-fertilization. Studies indicate that open pollination by honey bees significantly improves seed set, oil content and germination rates, leading to a substantial increase in crop productivity compared ~~to~~with self-pollination. However, various factors, such as pesticide use, habitat loss, and climatic variations, can negatively impact honey bee foraging activity, thereby affecting niger pollination and seed yield. Additionally, the strategic placement of beehives near niger fields can maximize pollination benefits while contributing to high-quality honey production, as niger nectar yields honey with a light color and distinct flavour~~flavor~~. The intricate interaction between honey bees and niger highlights the importance of pollination services in agricultural ecosystems and underscores the need for research-driven conservation initiatives. Understanding honey bee foraging dynamics in niger fields is essential for developing sustainable ~~agro ecosystems~~agroecosystems that optimize both seed yield and pollinator health. This review comprehensively examines the foraging behavior of honey bees on *G. abyssinica*, emphasizing ~~its~~their ecological and economic significance, the factors influencing pollination efficiency, and the critical role of pollinator conservation in ensuring sustainable crop production and biodiversity maintenance.

Keywords: ~~Cross-fertilization, agro-ecosystems~~Crossfertilization, agroecosystems, niger field, distinct flavour~~flavor~~ and pollinators.

1. Introduction

Niger (*Guizotia abyssinica* (L. f.) Cass.) is an important oilseed crop cultivated mainly in Ethiopia, India, and parts of Africa and Asia. It belongs to the Asteraceae family and is valued for its high-quality edible oil, which is rich in unsaturated fatty acids, making it beneficial for human health (Getinet and Sharma, 1996). ~~Apart from~~In addition to its economic ~~significance~~importance, niger plays a crucial role in ~~agro-ecosystems~~agroecosystems by serving as a vital nectar and pollen source for pollinators, particularly *Apis* spp. ~~*spp.*~~ (Ranganatha *et al.*, 2009). Pollination is a key factor influencing seed yield and quality in niger, as the plant exhibits varying degrees of self-incompatibility and benefits significantly from cross-pollination (Dwarka *et al.*, 2024[a,b,c,d,e]). Among pollinators, honey bees are the most efficient ~~due to~~because of their flower constancy, high visitation rates, and ability to forage over large areas. Niger is self-incompatible, with ~~100 per cent~~100% cross-pollinated crop (Dwarka *et al.*, 2022). The foraging behavior of honey bees on niger flowers is influenced by multiple factors, including diurnal variations, environmental conditions, floral rewards and competition with other pollinators (Lemanski *et al*~~et al~~., 2019; Parida *et al*~~et al~~., 2023; Singh & Mall, 2024). Understanding these behavioral patterns is essential for optimizing pollination efficiency, improving crop productivity, and ensuring sustainability in beekeeping practices (Dwarka *et al.*, 2022). Honey bee foraging is a complex process that involves nectar and pollen collection, the recruitment of foragers through ~~the~~ waggle ~~dance~~dances, and adjustments in response to climatic factors such as temperature, humidity, wind speed, and light intensity (Dwarka *et al.*, 2024[a,b,c,d,e]). Peak foraging activity typically occurs during mid-morning, when floral nectar secretion is at its highest level, and environmental conditions are most favour~~favor~~able. Additionally, honey bees demonstrate resource partitioning between nectar and pollen collection, with some foragers prioritizing one over the other ~~based~~ on the basis of colony requirements. The interaction between niger flowers and honey bees not only enhances seed production but also contributes to honey production, as niger nectar is known for its light color and distinct flavour~~flavor~~ (Dwarka *et al.*, 2022;2023[a,b,c]). However, several challenges, such as pesticide exposure, habitat loss, and competition from other pollinators, can impact honey bee foraging efficiency on niger crops (Dwarka *et al.*, 2022). Conservation strategies, such as establishing pollinator-friendly landscapes, adopting integrated

pest management practices and promoting beekeeping near niger fields, can enhance pollination services and ensure mutual benefits for both farmers and beekeepers (Mohana Rao *et al.*, 1981). This review explores the intricate foraging behavior of honey bees on *Guizotia abyssinica*, emphasizing its implications for crop yield, pollination ecology, and sustainable agricultural practices.

2. Importance of the niger in agriculture and ecology

Niger is an economically and ecologically significant oilseed crop widely cultivated in Ethiopia, India, and various parts of Africa and Asia. It plays a crucial role in the agricultural sector ~~due to~~because of its high-quality edible oil, which is rich in unsaturated fatty acids, making it a valuable source of nutrition for human consumption. The oil extracted from niger seeds is highly ~~sought after for~~desirable because of its light color, pleasant flavour~~flavor~~, and health benefits, particularly in maintaining cardiovascular health. Additionally, niger is an important source of livestock feed, as its by~~by-~~products, such as oilcake, are rich in protein and are used as nutritious animal fodder. ~~Beyond~~In addition to its economic benefits, niger contributes significantly to ecological sustainability by acting as a vital nectar and pollen source for pollinators, particularly honey bees (*Apis* spp. ~~*spp.*~~), which play a key role in enhancing crop productivity through pollination. The plant's bright yellow flowers attract a wide range of pollinators, including wild bees, butterflies, and beetles, thereby supporting biodiversity and ensuring cross-pollination, which is essential for improving seed yield and genetic diversity. Furthermore, niger cultivation is beneficial ~~in~~for soil conservation, as its deep root system helps prevent soil erosion and enhances soil fertility by ~~improving~~increasing the organic matter content. It is particularly well~~-~~suited for marginal lands and drought-prone areas ~~due to~~because of its resilience to poor soil conditions and ability to thrive with minimal inputs, making it an important crop for sustainable agriculture in regions facing water scarcity and soil degradation. Niger also plays a significant role in agroforestry systems, as it can be intercropped with cereals, legumes, and other crops, promoting biodiversity and increasing farm productivity. The interaction between niger and pollinators, especially honey bees, is a critical aspect of ecological balance, as the pollination services provided by bees not only improve niger seed production but also contribute to honey production, supporting the livelihoods of beekeepers. The nectar from niger flowers produces high-quality honey with distinct ~~flavor~~flavour~~flavors~~ and commercial value, making it an integral part of the apiculture industry. However, despite its numerous

benefits, niger cultivation faces challenges such as declining pollinator populations due to habitat loss, excessive pesticide use, and climate change, which threaten both agricultural productivity and ecological stability. Therefore, promoting sustainable farming practices, conserving pollinator habitats, and implementing integrated pest management strategies are essential to maintain the ecological balance and maximize the economic potential of niger cultivation. By integrating pollinator-friendly approaches and supporting beekeeping initiatives, farmers can significantly ~~enhance~~increase niger crop yield while ensuring the conservation of pollinators, which are indispensable to global food security and biodiversity. The importance of niger in agriculture and ecology extends beyond its role as a cash crop, as it serves as a cornerstone of sustainable farming, ecosystem resilience, and rural livelihoods, making it an invaluable resource for both present and future generations.

3. Honey bee species pollinating niger

Several species of honey bees contribute to the pollination of niger, including the following:

- *Apis mellifera* (~~Western~~western honey bee) – The most widely distributed and dominant pollinator (Dwarka, 2023).
- *Apis cerana indica* (Asian honey bee) – Common in South and Southeast Asia (Manchare *et al.*, 2019; Dwarka *et al.*, 2022).
- *Apis dorsata* (~~Giant~~gious honey bee) – Known for foraging at great heights (Dwarka *et al.*, 2022;2023[a,b,c]).
- *Apis florea* (~~Dwarf~~dwarf honey bee) – Often found in warm regions (Singh, 2015; Dwarka *et al.*, 2022;2023[a,b,c];2025).

Among these, *Apis mellifera* is the primary pollinator in most niger-growing regions.

4. Foraging activity of honey bees on niger

4.1. Foraging time and daily patterns

Honey bees exhibit diurnal foraging behavior, with peak activity occurring between 9:00 AM and 1:00 PM. Foraging begins in the early morning (6:00–7:00 AM) and gradually increases as the temperature ~~rises. Activity~~increases. The activity declines in the afternoon due to high temperatures, with minimal visits observed after 4:00 PM. The highest number of foraging visits occurs between 10:00 AM and 12:00 PM, corresponding with the maximum nectar and pollen availability (Dwarka, 2023).

4.2. Floral resource collection: nectar vs. pollen

Honey bees (*Apis* spp. ~~*spp.*~~) visiting niger flowers exhibit distinct foraging behaviors ~~based~~ on the basis of their colony's nutritional needs, collecting either nectar or pollen to sustain hive functioning and ensure brood development. Nectar serves as the primary carbohydrate source, providing the energy required for flight, thermoregulation, and colony maintenance, ~~while~~whereas pollen is the main protein source~~,~~ and is essential for larval growth and overall colony health. Foraging bees display specialization in resource collection, with individual bees often focusing either on nectar or pollen during a single foraging trip, a behavior that optimizes foraging efficiency and maximizes resource acquisition. Observations in niger fields indicate that nectar collectors outnumber pollen foragers, as niger is a prolific nectar producer, offering abundant sugar-rich floral secretions that attract large numbers of foragers. The nectar secretion rate varies throughout the day, with peak nectar availability occurring between 9:00 AM and 1:00 PM, ~~coinciding~~which coincides with the highest foraging activity of honey bees (Manchare *et al.,* 2019;Dwarka *et al.,* 2022,2025). The concentration of nectar sugars fluctuates depending on environmental conditions, including temperature, humidity, and soil moisture, which influence nectar volume and quality. Nectar foragers use their proboscis to extract nectar from ~~the~~ floral disc florets, storing it in their honey stomach before returning to the hive, where it is processed into honey through enzymatic activity and water evaporation. In contrast, pollen collectors actively gather pollen grains ~~using their~~via specialized body structures, such as branched hairs and corbiculae (pollen baskets), on their hind legs. The pollen grains adhere to the bees' bodies as they move from flower to flower, facilitating cross-pollination, which is crucial for seed development in niger. Pollen foragers exhibit specific behaviors, such as vibrating their bodies to dislodge pollen from anthers or scrubbing pollen ~~off~~from floral parts ~~using~~via their forelegs before ~~packing it~~being packed into pollen baskets. The proportion of nectar versus pollen collectors within a colony varies depending on colony requirements, brood-rearing status, and seasonal floral availability. During peak brood-rearing periods, the demand for pollen increases, leading to a ~~higher~~greater number of pollen collectors, whereas during nectar dearth periods, more bees shift their focus to nectar collection to maintain energy reserves. Studies have shown that pollen collection is generally more intensive in the morning, when pollen is freshest and most available, while nectar foraging continues throughout the day. Environmental factors such as temperature, humidity, and wind speed influence the efficiency of both nectar and pollen

foraging; for ~~instance~~example, high temperatures can reduce nectar secretion rates, whereas strong winds can hinder pollen collection by making it difficult for bees to land on flowers and dislodge pollen grains. Additionally, competition with other pollinators, such as wild bees, butterflies, and beetles, can impact resource collection, with honey bees demonstrating superior foraging efficiency due to their recruitment strategies and ability to communicate resource locations through ~~the~~ waggle ~~dance~~dances. The balance between nectar and pollen foraging is vital for both crop pollination and honey production, as higher bee visitation rates on niger flowers lead to increased seed set, improved oil content, and ~~enhanced~~**increased** genetic diversity in the crop. Moreover, honey produced from niger nectar is highly valued for its light color, mild flavour~~flavor~~, and high nutritional content, making niger an important nectar source for beekeepers. However, challenges such as habitat loss, pesticide exposure and climate change can disrupt floral resource collection, necessitating conservation efforts to protect both honey bee populations and niger crop yields (Manchare *et al.,* 2019;Dwarka *et al.,* 2022). By promoting pollinator-friendly agricultural practices, reducing pesticide use, and supporting sustainable beekeeping, farmers can ~~enhance~~increase both nectar and pollen foraging efficiency, ensuring optimal pollination services and maximizing the economic and ecological benefits of niger cultivation. The intricate relationship between honey bees and *Guizotia abyssinica* underscores the importance of understanding floral resource collection dynamics to sustain both apiculture and agriculture in pollinator-dependent cropping systems (Dwarka, 2023).

4.3. Foraging frequency and flower visitation rate

The foraging frequency and flower visitation rate of honey bees on *Guizotia abyssinica* (niger) are critical aspects of pollination efficiency, influencing both seed set and overall crop productivity. Honey bees ~~exhibit high foraging frequency~~frequently forage on niger flowers ~~due to the plant's~~because of their abundant nectar and pollen resources, making ~~it an~~them attractive food ~~source~~sources. Studies have shown that individual honey bees visit multiple flowers in rapid succession, with a single forager capable of visiting 8 to 12 flowers per minute, depending on environmental conditions, nectar availability, and competition from other pollinators. The high visitation rate of honey bees is attributed to their flower constancy behavior, where they consistently visit the same plant species within a foraging trip, ensuring effective cross-pollination and enhancing reproductive success in niger. The visitation rate of honey bees is influenced by several factors, including the time of day, floral density, temperature, humidity,

and wind speed. Peak foraging activity generally occurs between 9:00 AM and 1:00 PM~~,~~; when nectar secretion is ~~at its~~ highest, temperatures range between 25°C and 30°C, and weather conditions are optimal for flight (Dwarka *et al.*, 2022;2023[a,b,c]). As the day progresses and temperatures exceed 35°C, foraging activity tends to decline, as excessive heat can reduce nectar production and increase the risk of dehydration for foraging bees. Additionally, relative humidity plays a role in nectar concentration, with moderate humidity levels facilitating optimal nectar flow, thereby attracting more bee visits. Wind speed also affects foraging frequency, as strong winds above 15 km/h can reduce bee mobility, making it difficult for ~~them~~bees to maintain stable flight and land on flowers efficiently. The rate of flower visitation is also dependent on colony needs, as honey bees adjust their foraging behavior ~~based~~ on the basis of the nutritional requirements of their hive; during peak brood-rearing periods, a ~~higher~~greater proportion of foragers collect pollen, whereas during nectar dearth periods, bees prioritize nectar collection to sustain colony energy reserves. The presence of competing pollinators, such as wild bees, butterflies, and beetles, can influence honey bee foraging frequency, although honey bees generally outcompete other pollinators due to their advanced recruitment strategies, including ~~the~~ waggle ~~dance~~dances, which enables the effective communication of floral resource locations. Furthermore, the availability of alternative floral resources in the surrounding environment can impact the ~~foraging~~ frequency of foraging on niger, as bees may shift their preference to other plants if nectar availability fluctuates. Studies have demonstrated that higher bee visitation rates per flower correlate with increased pollen deposition, leading to improved seed yield, seed weight, and oil content in niger crops**,** highlighting the indispensable role of honey bees in pollination. Additionally, managed beekeeping practices, such as strategic hive placement near niger fields, have been shown to ~~enhance~~increase flower visitation rates, resulting in greater pollination efficiency and higher agricultural output. However, challenges such as habitat destruction, pesticide exposure, and climate variability can negatively impact foraging behavior, emphasizing the need for conservation efforts to maintain pollinator health and ensure sustainable agricultural production. The interplay ~~between~~among foraging frequency, flower visitation rate, and environmental factors underscores the complex yet essential relationship between honey bees and niger, reinforcing the need for pollinator-friendly agricultural practices to optimize both crop yield and ecosystem stability.

4.4. Influence of weather conditions on foraging

Weather conditions play ~~a~~ crucial ~~role~~roles in determining the foraging behavior, efficiency, and overall pollination effectiveness of honey bees (*Apis* spp. ~~*spp.*~~) on *Guizotia abyssinica* (niger). Temperature, humidity, wind speed, solar radiation, and rainfall significantly influence the frequency and duration of foraging trips, floral resource collection, and the ability of bees to ~~navigate~~travel between flowers and their hive. Among these factors, temperature has the most pronounced effect on honey bee foraging activity, with optimal foraging observed between 25°C and 32°C, when bees exhibit peak visitation rates and maximum floral resource collection (Dwarka *et al.*, 2022). At temperatures below 15°C, honey bee activity decreases as low temperatures impair wing muscle function and slow metabolic processes, making flight energetically inefficient. Conversely, extremely high temperatures above 35°C can lead to reduced foraging due to increased risk of dehydration and excessive energy expenditure for thermoregulation. The availability and secretion of floral nectar are also temperature~~-~~ dependent, with peak nectar production in niger flowers occurring during the morning hours, aligning with the most favour~~favor~~able temperature range for honey bee activity. Relative humidity influences both nectar concentration and pollen viability, with moderate humidity levels (~~around 50-70%~~**approximately 50–70%**) supporting optimal nectar secretion, ~~while~~whereas extremely low humidity causes rapid nectar evaporation, reducing ~~its~~nectar accessibility to foragers. High humidity, on the other hand, can lead to diluted nectar, requiring honey bees to expend more energy in water evaporation during honey production. Wind speed is another critical factor affecting honey bee foraging efficiency; gentle breezes below 10 km/h facilitate bee movement, ~~while~~whereas strong winds exceeding ~~15-20~~**15–20** km/h make flight difficult, leading to reduced floral visitation rates (Dwarka, 2023). Wind also affects pollen transfer, as excessive turbulence can dislodge pollen grains before bees have the chance to collect and transfer them, impacting the efficiency of cross-pollination in niger crops. Solar radiation influences bee activity, with clear, sunny conditions ~~enhancing~~increasing foraging intensity, ~~while~~whereas overcast skies and cloudy weather result in decreased flight activity due to reduced visibility and lower temperatures. Rainfall has a significant negative impact on honey bee foraging, as wet conditions make it nearly impossible for bees to fly, and water droplets on flowers dilute nectar or wash away pollen, reducing the availability of floral resources. Prolonged rainy periods can lead to extended foraging gaps, affecting colony nutrition and reducing pollination rates in niger fields. The interaction between these weather parameters determines the overall foraging success of

honey bees, and extreme climatic fluctuations caused by climate change pose a major challenge to pollination efficiency. Prolonged droughts can reduce nectar availability, leading to increased competition among foragers and potential shifts to alternative floral resources. In contrast, unpredictable rainfall patterns and temperature extremes can disrupt foraging schedules, affecting seed set and yield in niger crops. To mitigate these challenges, sustainable agricultural practices such as planting niger in regions with stable climatic conditions, conserving natural pollinator habitats, and avoiding pesticide use during peak foraging hours can help maintain healthy pollinator populations and ensure optimal foraging activity. Additionally, beekeepers can support honey bee colonies during adverse weather conditions by providing supplementary food sources, shading hives from excessive heat, and ensuring water availability near apiaries. Understanding the influence of weather conditions on honey bee foraging behavior is essential for optimizing pollination services, enhancing seed production in niger crops, and sustaining both agricultural productivity and pollinator health ~~in~~under changing environmental conditions. By integrating climate-adaptive beekeeping and pollinator-friendly farming practices, farmers and beekeepers can safeguard honey bee populations while ensuring the continued ecological and economic benefits of *Guizotia abyssinica* cultivation.

5. Impact of honey bee pollination on niger seed yield

5.1. Cross-pollination and seed set

Cross-pollination plays a vital role in the reproductive success and seed set of *Guizotia abyssinica*, a partially self-incompatible crop that significantly benefits from pollinator-mediated fertilization. Honey bees (*Apis* spp. ~~*spp.*~~) are the most efficient pollinators of niger, facilitating the transfer of pollen between flowers, thereby increasing genetic diversity, improving seed yield, and ~~enhancing~~increasing oil content. Niger flowers exhibit a composite inflorescence structure characteristic of the Asteraceae family, consisting of numerous small florets within a capitulum, each requiring pollen transfer for successful fertilization. Studies have shown that open-pollinated niger fields, where honey bees and other insect pollinators actively visit flowers, produce significantly ~~higher~~greater seed sets ~~compared to~~than self-pollinated or wind-pollinated fields do. The contribution of honey bees to cross-pollination is particularly crucial ~~in~~for increasing the number of filled seeds per capitulum, as self-pollination alone often results in poor seed development and reduced germination rates. The foraging behavior of honey bees ensures effective pollen transfer, as individual bees consistently visit multiple flowers on the same plant

before moving to adjacent plants, thereby promoting outcrossing. ~~Cross~~In niger, cross-pollination enhances various agronomic traits ~~in niger~~, including seed weight, oil percentage, and overall crop productivity, making honey bee pollination indispensable for commercial cultivation. The rate of cross-pollination in niger fields depends on several factors, including floral density, pollinator abundance, and the environmental conditions that influence bee activity. Peak cross-pollination occurs during the morning hours, when nectar secretion is at its highest level and bee foraging intensity is maximized. A higher density of honey bee colonies near niger fields significantly ~~boosts~~increases pollination rates, with recommended hive placements of two to five colonies per hectare to optimize seed set and yield. The presence of competing floral resources in surrounding landscapes can affect cross-pollination efficiency, as honey bees may divert their foraging efforts to alternative nectar and pollen sources if more attractive plants are available. However, the strong floral constancy exhibited by honey bees helps maintain consistent visitation to niger flowers, ensuring effective pollen transfer throughout the field. Seed set in niger crops is also influenced by climatic factors such as temperature, humidity, and wind speed, which can impact both pollen viability and pollinator activity. High temperatures can reduce pollen viability, ~~while~~whereas strong winds can interfere with pollination efficiency by dislodging pollen before it reaches receptive stigmas. Rainfall during the flowering period can wash away pollen, reducing the chances of successful fertilization. In contrast, optimal weather conditions with moderate temperatures, low wind speeds, and high pollinator activity result in increased seed set and improved crop performance. The role of managed beekeeping in enhancing cross-pollination is increasingly recognized, with farmers and beekeepers collaborating to strategically place hives near niger fields to maximize pollination services. In addition to honey bees, other pollinators, such as wild bees, butterflies, and beetles, contribute to cross-pollination, although their effectiveness is generally lower than that of managed honey bee colonies. ~~Conservation~~The conservation of pollinator habitats, reduction ~~of~~in pesticide usage, and ~~the~~ promotion of agroecological practices are essential strategies to sustain pollination services and ensure high seed yields in niger cultivation. The economic benefits of honey bee pollination extend beyond improved seed set, as beekeepers also benefit from high-quality niger honey, which is known for its light color, mild flavour~~flavor~~, and market value. Given the strong dependence of niger crops on insect pollination, research and extension efforts should focus on promoting pollinator-friendly farming practices, enhancing beekeeper-farmer partnerships, and

mitigating threats such as habitat loss and pesticide exposure. Sustainable management of pollinators is key to maximizing cross-pollination efficiency, ensuring food security, and maintaining ecosystem balance. Thus, the interplay between honey bees and *Guizotia abyssinica* underscores the ecological and economic importance of cross-pollination, making pollinator conservation an essential component of successful niger cultivation and agricultural sustainability (Chandrashekhar and Sattigi, 2009; Jayaramappa *et al.*, 2011; Dwarka *et al.*, 2023[a,b,c]).

5.2. Role of honey bees in enhancing genetic diversity

~~Honey bees~~Honeybees (*Apis* spp. ~~*spp.*~~) play a crucial role in enhancing the genetic diversity of *Guizotia abyssinica* by facilitating cross-pollination, which promotes gene flow between different plants and prevents the negative effects of inbreeding. As niger is a partially self-incompatible crop, natural pollination by honey bees ensures effective pollen transfer between flowers of different plants, leading to greater genetic recombination and variation within the population. This genetic diversity is essential for improving agronomic traits such as seed viability, yield potential, oil content and resistance to environmental stresses ~~like~~such as drought, pests and diseases. ~~Honey bees~~Honeybees exhibit strong floral constancy, meaning that they consistently visit niger flowers during foraging trips, ensuring efficient pollen transfer and ~~higher~~increased fertilization success. Their ability to forage over large distances enhances outcrossing rates, introducing new genetic material that strengthens the adaptability of niger crops to changing climatic conditions and soil types. Increased genetic variation also contributes to improved seed germination, plant vigor, and overall crop resilience, benefiting both farmers and breeders in ~~developing~~the development of superior niger varieties. Furthermore, honey bee-mediated pollination enhances biodiversity by maintaining the ecological balance within ~~agro ecosystems~~agroecosystems, supporting other pollinators and beneficial organisms. Therefore, conserving honey bee populations through pollinator-friendly farming practices, reducing pesticide exposure, and promoting managed beekeeping near niger fields is essential for sustaining genetic diversity, improving crop productivity, and ensuring the long-term success of niger cultivation in diverse agricultural landscapes.

6. Competition and floral resource partitioning

Floral resource competition and partitioning among pollinators play a significant role in shaping the foraging dynamics of honey bees (*Apis* spp. ~~*spp.*~~) on *Guizotia abyssinica*. Niger

flowers attract a diverse array of pollinators, including wild bees, butterflies, beetles, and other insects, leading to interspecific competition for nectar and pollen. Honey bees, ~~being~~which are highly efficient foragers, often dominate floral visits due to their advanced recruitment strategies, such as the waggle dance, which enables them to quickly locate and exploit rich nectar sources. However, to minimize direct competition, different pollinator species exhibit floral resource partitioning ~~based~~ on the basis of foraging time, flower preference, and resource utilization strategies. For ~~instance~~example, honey bees typically forage during peak nectar secretion hours (morning to early afternoon), ~~while~~whereas certain wild bees and butterflies exhibit different activity periods, reducing overlap in resource exploitation. Additionally, some pollinators specialize in pollen collection, ~~while~~whereas others focus on nectar, further promoting resource partitioning. The abundance and diversity of pollinators in niger fields can ~~enhance~~increase overall pollination efficiency by ensuring continuous pollen transfer, even ~~in~~under fluctuating environmental conditions. However, excessive competition, especially from aggressive floral visitors such as stingless bees or dominant wild bee species, may influence honey bee foraging behavior, potentially leading to shifts in flower visitation rates or reduced nectar foraging efficiency. Human-induced factors such as habitat destruction and pesticide use can further alter competitive interactions by reducing floral resource availability and disrupting pollinator populations. To maintain a balanced pollination network, conservation strategies such as preserving wildflower habitats, maintaining floral diversity, and minimizing pesticide exposure are essential. By promoting a diverse pollinator community and supporting honey bee populations, farmers can optimize floral resource partitioning, enhance cross-pollination, and maximize seed yield in niger cultivation while ensuring ecosystem stability and sustainability.

7. Factors affecting honey bee foraging efficiency on niger

7.1. Pesticide use

Excessive use of insecticides negatively affects honey bee populations by causing mortality and altering foraging patterns. Bee-friendly pesticides and integrated pest management (IPM) practices are essential ~~to sustain~~for sustaining pollinator health.

7.2. Floral density and field management

Fields with high floral density attract more bees and sustain longer foraging durations. Intercropping niger with bee-friendly crops enhances pollinator visits and improves overall farm productivity.

7.3. Beekeeping practices

Placing beehives near niger fields can maximize pollination benefits. Managed colonies improve pollination efficiency and enhance honey production.

8. Economic and ecological significance

The cultivation of *Guizotia abyssinica* holds substantial economic and ecological significance, benefiting farmers, beekeepers and ecosystems alike. Economically, niger is an important oilseed crop~~,~~ that is valued for its high-quality edible oil, which is rich in essential fatty acids and widely used for cooking, industrial applications, and export. The by~~by~~ products of niger seed processing, such as oilseed cake, serve as nutritious livestock feed, further contributing to agricultural sustainability. Honey bee pollination significantly enhances seed yield, oil content, and overall crop productivity, making beekeeping a profitable complementary enterprise for farmers cultivating niger. Niger honey, derived from the plant's abundant nectar, is prized for its mild flavour~~flavor~~, light color, and medicinal properties, providing an additional source of income for rural communities. Ecologically, niger plays a vital role in maintaining biodiversity by supporting a wide range of pollinators, including honey bees, wild bees, butterflies, and beetles, which contribute to overall ecosystem health. Its deep root system improves the soil structure, prevents erosion, and enhances soil fertility by contributing organic matter, making it an excellent rotational crop in sustainable farming systems. Additionally, niger cultivation requires minimal chemical inputs, reducing the environmental impact of intensive agriculture while promoting pollinator conservation. By fostering ecological balance and enhancing agricultural livelihoods, the economic and ecological benefits of niger cultivation highlight the need for sustainable farming practices, pollinator-friendly policies and increased investment in research to improve productivity and resilience ~~in~~under changing climatic conditions.

9. Conclusions

The foraging behavior of honey bees on *Guizotia abyssinica* is a crucial factor influencing seed yield and oil production. Honey bees exhibit diurnal foraging patterns, with peak activity in the late morning. Their role in cross-pollination enhances seed quality, genetic diversity, and overall crop productivity. Sustainable beekeeping practices, reduced pesticide usage, and habitat conservation can further strengthen the pollination efficiency of honey bees in

niger fields. Encouraging the presence of honey bees in niger cultivation can lead to mutual benefits for both agriculture and apiculture.

10. References

1. Dwarka, Chadar N, Katara VK , Thakur S, Shukla S, Parveen S, Maneesha and Ahirwar MK. Introduction to Insect Pests of Niger [*Guizotia abyssinica* (L.f.) Cass.] and Their Management: A Review. Journal of Experimental Agriculture International. 2024a;46(11): 835-841.
2. Dwarka, Ghugal SG, Katara VK, Panday AK and Chadar N. 2025. Assessment of various bee attractants on *Apis florea* Fabricius and their influence on seed yield of niger [*Guizotia abyssinica* (L.f.) Cass]. Annual Research & Review in Biology. 40(4): 67-73.
3. Dwarka, Ghugal SG, Thakur S, Panday AK. Evaluation of Various Bee Attractants on the Foraging Behavior of Indian Honey Bee (*Apis cerana indica*) and their Impact on the Seed Yield of Niger [*Guizotia abyssinica* (*L.f.*) Cass]. Advances in Research. 2024b;25(6);528-534.
4. Dwarka, Panday AK , Thakur S , Katara VK , Patel DK and Kurmi JP. Impact of different bee attractants on the attraction of Indian honey bee, *Apis cerana indica* and their impact on seed yield of niger, *Guizotia abyssinica* (L.f.) Cass, crop. Plant Archives. 2024c;24(2); 255-258.
5. Dwarka, Panday AK , Thakur S and Katara VK. Study on the Effect of Bee Attractants on the Giant Honey Bee, *Apis dorsata* and their Effect on Niger [*Guizotia abyssinica* (L.f.) Cass] Seed Yield Journal of Experimental Agriculture International. 2024d;46(7); 903-908.
6. Dwarka, Panday AK and Saxena AK. To study the effect of bee attractants on the attraction of giant honey bees (*Apis dorsata*) and their impact on seed yield of Niger (*Guizotia abyssinica*) crop. The Pharma Innovation Journal. 2022;11(12): 866-868.
7. Dwarka, Panday AK, Saxena AK, Jain S, Marabi RS and Sahu R. Impact of different weather parameters on the population of pollinators visited on Niger flowers. The Pharma Innovation Journal. 2023a;12(7): 619-621.
8. Dwarka, Panday AK, Saxena AK, Jain S, Sahu R and Marabi RS. The relative abundance of insect pollinators/visitors in Niger (*Guizotia abyssinica*) crop. The Pharma Innovation Journal. 2023b;12(2): 3579-3581.
9. Dwarka, Panday AK, Tare S, Thakur S, Katara VK. Effect of Bee Attractants on the Attraction of *Apis dorsata* and their Impact on Seed Yield of Niger *Guizotia abyssinica* (L.f.) Cass Crop. Journal of Scientific Research and Reports. 2024e;30(6):420- 426.
10. Dwarka, Saxena AK, Panday AK, Jain A and Marabi RS. Succession of different insect pollinators on Niger flowers grown under different dates of sowing. The Pharma Innovation Journal. 2023c;12(7): 622-627.
11. Dwarka. 2023. Study of foraging behavior of insect pollinators/visitors and its effect on yield attributes of niger crop, *Guizotia abyssinica* (L. f.) Cass. Ph.D. thesis JNKVV, Jabalpur, MP.

12. Getinet A and Sharma SM. 1996. Niger, *Guizotia abyssinica (L.f.)* Cass. Promoting the conservation and use of underutilized and neglected crops. Institute of Plant Genetics and Crop Plant Research. International Plant Genetic Resources Institute, Rome.
13. Jayaramappa Kract V, Pattibhiramaiah M and Bhargava HR. Influence of bee attractants on yield parameters of Ridge gourd (*Luffa acutangulus* L.) (Cucurbitaceae).World Applied Science Journal. 2011;15(4);547-462.
14. Manchare RR, Kulkarni SR and Chormale TS. Effect of bee attractants on foraging activities of Indian bees *Apis cerena indica* in bitter gourd (*Momordica charantia* L.). Journal of Entomology and Zoology Studies. 2019;7(5); 468-472.
15. Mohana Rao, GM, Lazar M and Suryanarayana MC. Foraging behaviour of honeybees in sesame (*Sesamum indicum* L.). Indian Bee Journal. 1981;43:97-100.
16. Ranganatha ARG, Tripathi A, Jyotishi A, Paroha S, Deshmukh MR and Shrivastava N. 2009. Strategies to enhance the productivity of sesame, linseed and niger. In: Proceedings of Platinum Jubilee Celebrations, UAS, Raichur.
17. Singh RS, Amrendra Pratap B, Singh Singh DV. Abundance and foraging activity of bee visitors to pigeonpea. Progressive Agriculture. 2015;15(1):116- 119.
18. Lemanski, N. J., Cook, C. N., Smith, B. H., & Pinter-Wollman, N. (2019). A multiscale review of behavioral variation in collective foraging behavior in honey bees. *Insects*, *10*(11), 370.
19. Parida , N., Sahoo , B. K., Satapathy, S. N., Singh , S., Paikaray, S. S., & Mohapatra, A. (2023). Studies on Foraging Behaviour of Honeybees on Flowers of Rapeseed Crop. *International Journal of Environment and Climate Change*, *13*(11), 707–712.
20. Singh, M., & Mall, P. (2024). Biodiversity and Foraging Behaviour of Major Insect Pollinators on Some Fruit Crops. *Journal of Scientific Research and Reports*, *30*(5), 879–888.